Polluting Industrialization

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Abstract

Recently, many contributions have focused on the relationship between capital accumulation, growth and population dynamics, introducing fertility choice in macro-dynamic models. In this paper, we go one step further highlighting also the link with pollution. We develop a simple overlapping generations model with paternalistic altruism according to wealth and environmental concerns. One can therefore explain a simultaneous increase of capital intensity, population growth and pollution, namely a polluting industrialization. We show in addition that a permanent productivity shock, possibly associated to technological innovations, promotes such a polluting development process, escaping a trap where the economy is relegated to a low capital intensity, population growth and pollution.

JEL classification: J13, 044, Q56.

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1 Introduction

According to the hysteretic nature of the Environment,[1] contemporary actions condition the wellness of future generations. Consequently, it seems crucial to understand its long term trend. Historically, the development of human activities has generated a huge increase in pollution, starting with the industrialization. Actually, this event represents a break in the effects of mankind on his environment and even the beginning of a new geological era: the *Anthropocene*. This term, coined by Crutzen and Stoermer (2000),[2] describes the current geological epoch where the impacts of human activities on earth and atmosphere are become predominant. Still informal, the large diffusion of this expression in the geological literature and its recognition by the Stratigraphic Commission of the Geological Society of London show the importance of the phenomenon and lead us to look into this period of development.[3]

The awareness of this process is confirmed by the extensive literature in environmental economics (e.g. Howarth and Norgaard (1992), Gradus and Smulders (1993), Michel and Rotillon (1995) or Xepapadeas (2004)). Nevertheless, as emphasized by Brock and Taylor (2005), "the relationship between economic growth and the environment is and may always remain controversial". While some economists see the pollution-income relationship (PIR) as monoticaly positive, others see it as an inverted U-shaped curve, also known as the environmental Kuznets curve (EKC), discovered by Grossman and Krueger (1991) and so called by Panayotou (1995). According to the second group, the economic growth increases pollution in the early stages of development, but beyond some level of income per capita, the trend reverses, so that at high income levels, economic growth leads to environmental improvement. Whereas there exists theoretical explanations to this phenomenon: definition of environment as a luxury good, technological progress making able to be less polluting, or sectoral change diminishing the share of industry in favor of services *etc.* There are also theoretical contestations for each argument: pollution decrease only per unit of output and not in absolute levels, pollution-intensive industry are exported to the least developed countries *etc.* ; at witch add a lack of empirical proof, since the relation is verified only for some pollutants.[4]

Here, we will introduce an important missing dimension inside this debate: the demographic one. Indeed, many papers emphasize that population is a key element in the economic development process (e.g. Ehrlich and Lui (1997), Galor and Weil (2000) or Galor (2005)). Despite these two abounding literatures and the consensus on the existence of a link between them, economists have rarely focused on the relationship between population, economic and pollution growth, as underlined by Chu and Yu (2002) and Robinson and Srinivasan (1997). Those are the reasons why we are interested in the role of population. More precisely, we will study it for the first part of the PIR where pollution and economic growth evolve in the same way. We want to look at the effect of endogenous population growth *à la* Barro and Becker (1989) on factors accumulation during industrialization.

Our motives for focusing on this complex link, at low development levels, stems from several intuitive elements. Concerning growth and population, we have observed empirically a positive adjustment of population to an increase in income per capita due to industrialization.[5] However, the population evolution has allowed a very important increase in production through a heavy increase in demand, favoring cumulative growth process (Bairoch (1997)). About the connection between growth and pollution, we know that the production process often causes environmental damages, but

[1] The pollution effects continue over time, even after cause end.

[2] Crutzen is the Nobel prize winning atmospheric chemist (1995) for discovering the effects of ozone-depleting compounds.

[3] *See Zaasiewicz and al. (2008).*

[4] This debate is summarized in Van Alstine and Neumayer (2010) for example.

[5] This is shown in the study directed by Wrigley and Schofield (1981).

as Dasgupta (2003) reminded, environment being widely seen as a luxury when a country is richer, environmental concerns are also stronger. With regard to population and pollution, on one hand population growth generates a priori more pollution and resources depletion but on the other hand, pollution, affecting wellness has an influence also on demographics behaviors.

The aim of this paper is to develop a simple growth model with endogenous fertility and pollution change being able to understand the evolution of capital intensity (a proxy of GDP per capita), population growth and pollution, during the industrialization process.[6] In order to study the intergenerational aspects, we are going to employ an overlapping generations model, due to Allais (1947), Samuelson (1958) and Diamond (1965). This standard tool was used more lately in environmental economics by seminal papers as John and Pecchenino (1994) that pointed out that "such a demographic structure permits analysis of situation where agent's action have consequence that outlive them". So, this kind of model turns out to be well suitable for pollution issues and our long-term environmental analysis, allowing to look at the external effects of finite-life agents' choices on environment. The question, which arises then, concerned the environmental bequest, deriving from a trade-off between capital bequest, consumption's choices and ecological impacts.

We consider an overlapping generations model with pollution in which altruism has a central role as Jouvet, Michel and Vidal (2000). But contrary to these authors and for more realism, the altruism is paternalistic: parents experience a warm glow from leaving bequest to their offspring, i.e. joy-of-giving. This legacy is multiple and related to the amount of wealth parents want to leave to heirs and to environmental perspective, illustrating their volition to pass on an favorable environment to their children. The first is classic and called here the wealth's altruism, while the second is new and constitutes an environmental altruism. Regarding this second type of altruism, it is important to notice that households take care about both natural and economic environment. We set, therefore, a perception index of pollution adjusted to development: when households anticipate an increase in standard of living, they tolerate, as an acceptable compensation, a higher level of pollution. This second altruism is thus not a standard green altruism but an index of future generations' well-being according to natural and economic environment preoccupations. Note that it allows the existence of a positive link between wealth and pollution, corresponding to the facts.

Against the prejudice about environment problems recognition in the era studied, the environmental altruism is justified. Indeed, pollution is an old issue: despite its contemporary-looking, this word exists since the 12th century and is a matter of concern for a long time.[7] As nowadays, its definition represented multifaceted realities but was not identical, evolving over time with knowledge and technology. It concerned especially urban sanitary issues, resource depletion (particularly deforestation), but also later, water and air pollution. Studying the first stages of development, we will use this large definition and look at local pollution related to agrarian and urban concerns.

We do not take into account explicitly mortality in our model, meaning that fertility and population growth are represented by the same variable, as in well-known contributions like Galor and Weil (2000). This assumption is supported by the stage under consideration where birth rate and population growth experienced a common trend. In addition, at this time, the birth rate increased while the decrease of mortality was weak.[8] Actually, we consider a fertility rate in net terms which represents the desirable number of survival offspring that agents choose. Parents know that there is

[6] In this paper, we are only interested in the first stages of development. So, the period under consideration stops before the demographic transition.

[7] E.g. in France, from the 12th and 13th centuries, monarchs as Philippe Auguste or Louis IX, but also seigneurial authorities or municipal magistrates, denounced the nuisances on their multiple aspects. See Leguay (1999) for further examples.

[8] These two facts are illustrated by the experience of England. See Galor (2005) and Wrigley and Schofield (1981).

infant mortality but they can not control it, as medicine was not enough developed. When income increases, there would have an increase in the number of children who will survive to the childhood.

The benefits of having children through altruisms are weighted against a cost. For that, we adopt a constant cost of rearing children in terms of final good, appropriate for the early stages of development on which we are interested.[9] It allows wealth and population to evolve in the same direction, as shown by empirical studies on this era.

These key features of the model allow us to show that if the economy has not too low initial conditions on wealth and population size, it experiences a polluting industrialization, i.e. the convergence to a steady state with high capital intensity, population growth and pollution. Indeed, the constant cost of rearing children in terms of final good promotes that an increase in population size goes with the rise in capital intensity. Moreover, environmental altruism involves that households agree that their children face a less healthy environment if the economy is more developed, i.e. the population growth is larger. On the contrary, if the economy starts with too low initial conditions, it may be relegated to a poverty trap characterized by a low capital intensity, population growth and pollution. In this case, the wealth level is not large enough to engage a growth process. Finally, we demonstrate that a permanent technological shock promotes a polluting industrialization process, being able to escape the economy from the poverty trap and to converge to the industrial steady state characterized by high capital intensity, population growth and pollution.

The paper is organized as follows. The next section presents the overlapping generations model with paternalistic altruism, endogenous fertility and pollution. Section 3 provides our explanation of polluting industrialization, analyzing steady states, dynamics and the effect of a permanent technological shock. We conclude in Section 4, while several technical details are relegated to an Appendix.

2 The Model

We present a simple overlapping generations model which allow us to analyze the trend of capital intensity, population growth and pollution during the early stages of the process of development, i.e. what we call a polluting industrialization. Our explanation is mainly based on the behavior of households, which make choices according to their two motives of altruism, a wealth one and an environmental one. Hence, to have a convenient model, the production sector and the pollution change are kept as simple as possible.

2.1 The Environment

Despite its contemporary-looking, environmental deterioration is an old issue. Indeed, the word pollution exists since the 12th century and numerous official reactions against pollution issues have been observed since this time.[10]

If the environment refers nowadays to multiple concepts, like sustainable development, biodiversity, natural resource, or air, water and ground qualities, it was also the case in the first stages of development. The same form of generality persists when we focus on developing or industrializing countries, only the different facets of definition change (evolving with knowledge and technology).

[9] In this paper, we focus on the industrialization process. Our study stops before the demographic transition, which leads to the modern economy (*i.e.* the current developed countries level). That is the reason why we choose this cost in good rather than a cost in time, which would introduce a quality-quantity trade-off in terms of child, corresponding to the demographic transition.

[10] E.g. in France, from the 12th and 13th centuries, monarchs as Philippe Auguste or Louis IX, but also seigneurial authorities or municipal magistrates, denounced the nuisances on their multiple aspects. See Leguay (1999) for further examples.

In pre-industrial societies, pollution can mainly be appreciated from an agrarian point of view with resource depletion (e.g. deforestation) or insufficiency of agricultural production, but also from an urban one referring especially to sanitary issues. Then, with development toward industrial regime, other problems, closer to present one, are added as air and water pollution, because of the inconveniences of the industrial production process. Consequently, we will consider a large definition of Environment, including all these aspects. Environmental quality will be described by an aggregate index, as usual in most of the macro-dynamic models. More precisely, we use an index of pollution stock P_t which represents the environmental damages (opposed to environmental quality).[11] Moreover, we privilege a local view of pollution which evolves according to the following law of motion:

$$P_{t+1} = (1-\alpha)P_t + aN_t c_t \tag{1}$$

With P_0 the pollution level in t=0 given, N_t the population size and c_t the individual consumption, at period t.

The accumulation of pollution is due to aggregate consumption $N_t c_t$, with $a > 0$ the rate of pollution flow. We want to center our analysis on households behavior, consequently we choose a polluting consumption. This usual assumption allows us to look at the effect of consumers on environment more directly than with polluting production[12]. The environment regenerates at a rate $\alpha \in (0,1)$, i.e. in the absence of human activity, it can reconstitute itself partly. Such a phenomenon is called ecological resilience and refers to the reversible part of pollution. Note that our formulation is similar to the one of John and Pecchenino (1994), without environmental maintenance, which is done in our model only through consumption choice.

2.2 Households

Households' behavior plays a key role in our analysis. We consider a representative family composed to N_t adults and their children. The choices are made at the family level such that: the head of the family makes choices, knowing that his relatives has the same preferences than him ; these choices are then followed by all family members of his generation.[13]

In order to examine the intergenerational consequences of choices, we develop an overlapping generations model with endogenous fertility and paternalistic altruism. With this form of altruism, parents derive utility not from their children's utilities (corresponding to dynastic altruism), but from the size of the wealth they leave to them. The bequests are related to parental view on what is good for their heir, and to the pleasure they derive from giving. The reason why we choose this paternalistic altruism or impure one as called by Andreoni (1989) rather than a dynastic or pure one *à la* Barro(1974), is the analytical convenience of this form, allowing a non optimal framework, essential to analyze externalities across generations. Moreover, the joy-of-giving is more realistic than the pure altruism which requires human foresight capacities "that are beyond capacities of the most prescient" as Becker (1993) admits.

We grant a fundamental place to altruism in our model, studying two types of legacy: a wealth one, equivalent to a classic joy of giving (i.e. in term of capital bequest), and an environmental one, taking into account natural and economic environment. Each adult is interested in what he passes down to his children: a capital inheritance and a favorable environment relatively to the development level (embodied by an environmental quality index). Thus, we will shed light on intergenerational

[11] Pollution stock is defined as the opposite of environmental quality .

[12] The same choice was done by John and Pecchenino (1994), John and al. (1995)), Ono (1996)*etc.*

[13] Our formulation is in the spirit of the dynastic framework of choice *à la* Ramsey (1928) but with finite-lived agents.

transmissions of the capital and the environment and theirs interplays with other private decisions, concerning consumption and children, over agent's life-cycle.

About environmental concerns, we assume that agents take into account a perception index of environmental damages adjusted for family size. Here, family size plays the role of a family prosperity index (the coming family income): larger the family is, larger the workforce is and larger the income is.[14] Thus, households make a trade-off between a lower level of pollution and a higher level of family wealth. When they expect higher standards of living, they tolerate a higher level of pollution as an acceptable compensation. As illustrations of this compromise, Bairoch (1997) observes that more than a break with the social and family backgrounds, migration toward city associated with the industrialization process of England, was accompanied by urban excess of death and appalling life conditions. Williamson (1985) and Brown (1990) found also that a large part of the raise in wage in the factory sector, during industrialization, appears to be explained as compensation for poor working and living conditions. At an aggregate level, the family prosperity index is comparable to a development index, considering the important link between economic and demographic growths in the era studied.[15] An increase in population generates a larger number of producer and consumer, which favors the economic growth process. Finally, note that this environmental altruism is not per se a barrier to economic development and will allow the existence of a positive relationship between wealth and pollution, corresponding to the first step of the environmental Kuznets curve.

Households live two periods, childhood and adulthood, but take all decisions during their second period of life. The utility of a household, born in $t-1$, depends on his consumption level during his second period of life (c_t), on his number of children (n_t), on the amount of capital kept at life-ending with the intention of bequeath it to his children ($x_t \equiv n_t k_{t+1}$), and finally on the index of pollution stock he leaves to future generations ($\Pi_{t+1} \equiv P_{t+1}/N_{t+1}$).

We choose to represent preferences through a specified utility function to have a simple model, which captures, however, the mechanisms we want to emphasize. The preferences of an agent born in $t-1$ are defined by the following utility function:

$$\ln c_t + \epsilon_1 \ln(x_t) - \epsilon_2 n_t \frac{\Pi_{t+1}^{1+\mu_3}}{1+\mu_3} \tag{2}$$

where $\epsilon_1 > 0$ and $\epsilon_2 > 0$ are the paternalistic altruism factors on wealth and environmental concerns, respectively, and $\mu_3 > 0$. Note that $\epsilon_2 \Pi_{t+1}^{1+\mu_3}/(1+\mu_3)$ can be interpreted as a disutility of relative pollution per child.[16]

During their first period of life, agents are children and economically inactive, but they generate an individual cost of rearing, $\beta > 0$, to their parents. We assume a constant cost in terms of final good, which allows wealth and population to evolve in the same direction. The wealthier people are, the more children they want to have. Such an assumption is appropriate for the pre-industrial period, more than the alternative in time that would introduce a quality-quantity trade-off in term of child leading to a demographic transition, away from our point.[17] Moreover, this usual assumption, used by Becker and Barro (1988), is justified empirically in this era: the cost of raising a child seems to remained quite stable and weak during this period. Indeed, it corresponds to a simply cost necessary

[14]Being in a full employment framework without technological progress, economic growth will be driven by population growth in the long run, as usually in exogenous growth model.

[15]See Galor (2005).

[16]We choose a utility function specification such that there is "distaste effects" of pollution on consumption ($U_{cP} < 0$) and on the number of children ($U_{nP} < 0$): an increase in pollution implies a decrease in marginal utility to consume and to have children. See Michel and Rotillon (1995).

[17]Our paper deals with first stages of development process. Our study stops before the demographic transition, representing the beginning of the modern economy (current developed countries level).

to ensure children's subsistence, notably because of child labor and the lack of education even with industrialization.[18]

During their second period of life, agents become adults and are subject to a budget constraint. Each agent supplies inelastically one unit of labor remunerated at the wage rate w_t and inherits an amount of capital k_t from their parents remunerated at the return R_t. These incomes are shared between consumption (c_t), bequest (x_t), and children rearing ($n_t\beta$). Thus, an adult faces the following budget constraint:

$$c_t + n_t(k_{t+1} + \beta) = R_t k_t + w_t \tag{3}$$

Finally, the number of adults N_t in period t is given by the number of adults N_{t-1} in $t-1$ multiplied by the number of children n_{t-1} they choose to have at this period. Therefore, the evolution of population is given by:

$$N_t = n_{t-1} N_{t-1} \tag{4}$$

with $N_0 = 1$ given. We can observe that intergenerational externalities intervene in the equation of pollution: my choice in term of number of children has an effect on my grandchild's pollution.

Maximizing the utility function (2) subject to the budget constraint (3), the pollution change (1) and the evolution of population (4) lead to two first order conditions. The first one corresponds to the agent's trade-off in term of capital and is given by:

$$c_t^{-1} = \epsilon_1 x_t^{-1} + \epsilon_2 \; a \; \Pi_{t+1}^{\mu_3} \tag{5}$$

Reducing consumption to increase capital bequest has a cost corresponding to the marginal utility (c_t^{-1}) and a direct benefit through the marginal utility (x_t^{-1}) weighted by the altruism factor ϵ_1. However, a second benefit goes through environmental quality: consumption being polluting, increasing bequest generates a marginal gain through the decrease of pollution. Hence, individuals make their choice between consumption and bequest according to the utility provided directly by this choice, but also according to the welfare associated to environmental altruism.

The second trade-off summarizes the choice in term of children:

$$(k_{t+1} + \beta)\ \left(c_t^{-1} - \epsilon_2 \; a \; (\Pi_{t+1})^{\mu_3}\right) = \epsilon_1 \; n_t^{-1} + \epsilon_2 \left[(\Pi_{t+1})^{1+\mu_3} - \frac{(\Pi_{t+1})^{1+\mu_3}}{1+\mu_3} \right] \tag{6}$$

To understand this choice, we have again to interpret the marginal costs and benefits of having children. Concerning the costs of having more children, there is the renunciation to consumption ($(k_{t+1} + \beta)c_t^{-1}$) due to the increase of bequest and rearing cost. This effect is, nevertheless, mitigated by the fact that a lower consumption corresponds also to a benefit in term of environmental quality because households pollute less ($\epsilon_2 \; a \; (\Pi_{t+1})^{\mu_3}(k_{t+1} + \beta)$). Concerning the marginal benefits, an adult enjoys to have children through his altruism in terms of wealth ($\epsilon_1 \; \frac{1}{n_t}$). A second marginal benefit derives from relative environmental altruism. For a given pollution stock, an increase of the fertility rate corresponds to a lower pollution stock per capita, which is the index perceived by agents ($\epsilon_2 \Pi_{t+1}^{1+\mu_3}$). This effect is, however, reduced by the increasing weight associated to the pollution index: when adults have more children, they are more affected by pollution because they want a healthy environment for them ($\epsilon_2 \frac{(\Pi_{t+1})^{1+\mu_3}}{1+\mu_3}$).

[18] Actually, child labor did not stop with industrialization but intensified (Horrel and Humphries (1995)). Concerning education, although the industrial revolution is a technical revolution, in its first stages it satisfied oneself with an unskilled workforce and was not accompany by majors progress in education (Bairoch (1997) or Galor (2005)).

Using the first trade-off (5), equation (6) rewrites:

$$\Pi_{t+1} = \left[\beta \frac{\epsilon_1}{\epsilon_2} \frac{1+\mu_3}{\mu_3} x_t^{-1}\right]^{\frac{1}{1+\mu_3}} \equiv g(x_t) \tag{7}$$

Remark 1 *g is a decreasing function, showing that there is a decreasing relation between the pollution index Π_{t+1} and x_t, meaning that there is a positive link between wealth's bequest and the perceived environmental quality.*

Substituting (7) into (5), we obtain:

$$c_t = \left[\epsilon_1 \, x_t^{-1} + \epsilon_2 \, a \, \left[\beta \frac{\epsilon_1}{\epsilon_2} \frac{1+\mu_3}{\mu_3} x_t^{-1}\right]^{\frac{\mu_3}{1+\mu_3}}\right]^{-1} \equiv h(x_t) \tag{8}$$

Remark 2 *h is an increasing function, revealing the positive relationship between consumption (c_t) and bequest (x_t).*

Hence, the optimal behavior of households can be summarized by two equations, which determine the connections between individual consumption (c_t), wealth's bequest (x_t) and pollution index (Π_{t+1}). It is important to notice that both forms of altruism are needed for our analysis. Indeed, without wealth's altruism, there is no capital, i.e. no production. Without environmental altruism, the net benefit of having children is lower than the one of investing an adding unit in capital. In this case, the economy degenerates again.

2.3 Firms

Since our model is centered on household's behavior, we choose to set an easily understandable production sector and assume then that a unique final good is produced by a representative firm. The production is given by $Y_t = AK_t^s N_t^{1-s}$, where K_t is aggregate capital, N_t aggregate labor, $A > 0$ the total productivity of factors and $s \in \{0, 1\}$ the capital share in total income. The economy is perfectly competitive. From profit maximization, we get the two standard first order conditions of firm program:

$$R_t = sAk_t^{s-1} \quad \text{and} \quad w_t = A(1-s)k_t^s \tag{9}$$

where R_t denotes the real return to capital,[19] w_t the real wage and $k_t \equiv K_t/N_t$ the capital intensity.

2.4 Intertemporal equilibrium

We end this section with the definition of an intertemporal equilibrium. Substituting (9) in the budget constraint (3), we get the resource constraint:

$$c_t + x_t + \beta n_t = A \, k_t^s \tag{10}$$

Using $\Pi_{t+1} = P_{t+1}/N_{t+1}$ and reminding that $N_{t+1} = n_t N_t$, we can rewrite the evolution of pollution (1) as:

$$n_t \Pi_{t+1} = (1-\alpha)\Pi_t + ac_t \tag{11}$$

Finally, using functions g and h, an intertemporal equilibrium can be defined as:

[19] Since the size of one period is quite long, there is full depreciation of capital.

Definition 1 *Given the initial conditions* $k_0 \geqslant 0$ *et* $\Pi_0 = \frac{P_0}{N_0} \geqslant 0$*, an intertemporal equilibrium is a sequence* (x_{t-1}, k_t)*, for all* $t \geqslant 0$*, such that the following dynamical system (12) is satisfied:*

$$\left\{ \begin{array}{rcll} h(x_t) + x_t + \beta \frac{x_t}{k_{t+1}} & = & A\, k_t^s & (A) \\ \frac{x_t}{k_{t+1}}\, g(x_t) - \ a\, h(x_t) & = & (1-\alpha)\, g(x_{t-1}) & (B) \end{array} \right. \tag{12}$$

We notice that, at period t, the two variables $x_{t-1} = n_{t-1} k_t$ and k_t are predetermined.[20]

3 An explanation of polluting industrialization

Using the simple overlapping generations model with altruism and endogenous fertility developed above, we will be able to exhibit what we call a polluting industrialization. We start with some preliminary results related to the existence of steady states. Then, analyzing dynamics, we show that there is sets of initial conditions such that the economy experiences a polluting industrialization , i.e. an increase of capital intensity, population growth and pollution. Finally, we will look out the effect of a permanent technological shock in the case where the economy is stuck on a pre-industrial trap with low levels of capital intensity, population growth and pollution.

3.1 Preliminary results: steady states analysis

As a preliminary study of dynamics, the steady state analysis will allow us to understand some long-term trends of the economy. We will show the existence of two steady states. The first one is characterized by a lower capital intensity, population growth and pollution and will determine a poverty trap. Whereas the second one will represent the outcome of an industrialization process with larger capital intensity, population growth and pollution than the pre-industrial state.

According to the previous section, we define:

Definition 2 *A steady state equilibrium of the dynamical system (12) is defined as a solution,* (x, k) *satisfying:*

$$\left\{ \begin{array}{rclcl} k & = & \left[\frac{1}{A}\left[\beta(1-\alpha) + x + \left(1 + \frac{\beta a}{g(x)}\right) h(x)\right]\right]^{\frac{1}{s}} & \equiv & \Psi_1(x) \\ & & & & \\ k & = & \frac{x}{(1-\alpha) + a\ h(x)\ g(x)^{-1}} & \equiv & \Psi_2(x) \end{array} \right. \tag{13}$$

To show the existence and characterize the solutions of (13), we begin by exhibiting some properties of $\Psi_1(x)$ and $\Psi_2(x)$:

Lemma 1
1. Ψ_1 *is a strictly increasing function, where* $\Psi_1(0)$ *is strictly positive and* $\lim_{x \to +\infty} \Psi_1(x) = +\infty$.
2. There exists a value x^* *such that* $\Psi_2(x)$ *is increasing for all* $x \leqslant x^*$ *and decreasing for all* $x \geqslant x^*$*. Furthermore,* $\Psi_2(0)$ *is equal to zero and* $lim_{x \to +\infty} \Psi_2(x) = \beta\, \epsilon_1\, (1 + \mu_3)/\mu_3 > 0$.

Proof. See Appendix 1. ∎

This lemma allows us to show the coexistence of two steady states as it is illustrated in Figure 1 and shown in the following proposition.

Proposition 1 *For* β *sufficiently weak, there exist two steady states: a pre-industrial one* (x_1, k_1) *and an industrial one* (x_2, k_2)*. The latter equilibrium is characterized by a larger:*

[20] x_{t-1} is predetermined because $x_{t-1} = g^{-1}(\Pi_t)$ and Π_t is predetermined.

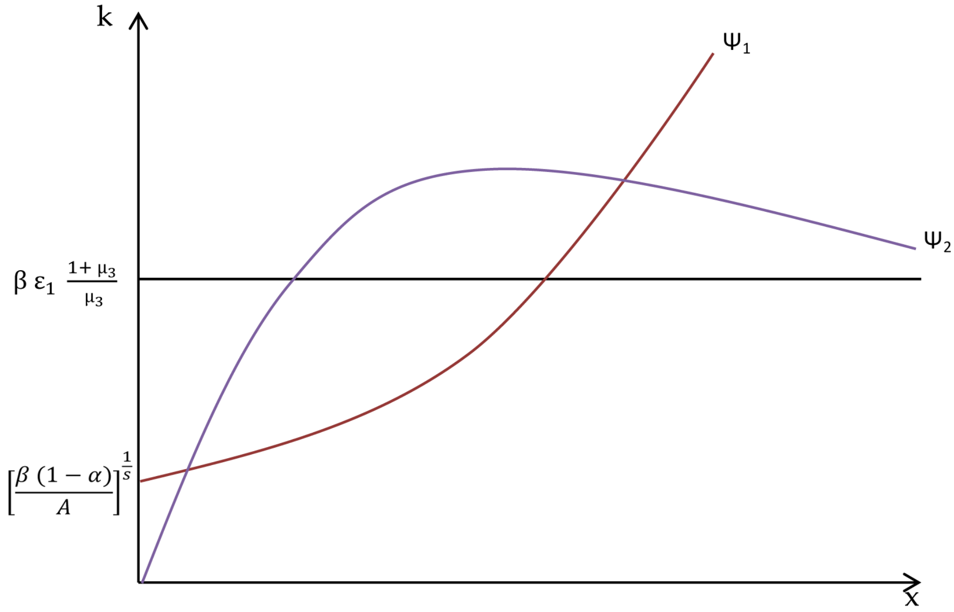

Figure 1: Representation of $\Psi_1(x)$ and $\Psi_2(x)$ and existence of two steady states

- *capital intensity* ($k_2 > k_1$)
- *bequest* ($x_2 > x_1$)
- *individual consumption* ($c_2 > c_1$)
- *population growth* ($n_2 > n_1$)
- *pollution stock* ($P_{2t} > P_{1t}$)

Proof. See Appendix 2. ■

We observe that the industrial steady state has a larger capital intensity, individual consumption, fertility growth[21] and pollution stock. Hence, it perfectly corresponds to the long-term state of a regime initiated by industrialization and pointing up a high capital intensity, and therefore, GDP per capita, but also a large population growth and a deterioration of environment quality. Note that, about the relationship between environmental quality and capital intensity, our results contrast with literature (e.g. John and Pecchenino (1994)), being negative. Our model is actually appropriate for developing countries and allow to represent the first part of the environmental Kuznets curve.

From a theoretical point of view, two key mechanisms lead to the industrial equilibrium. Firstly, because there is a constant rearing cost in term of goods, a higher fertility rate is compatible with a higher wage, and therefore capital intensity. Secondly, the environmental altruism tolerates a higher pollution if development goes up too. This explains that a higher capital intensity and population growth are in accordance with a higher pollution, and allows us to reproduce elements observed historically.

3.2 Transitional dynamics

In this section, we enrich the study of steady state multiplicity with the analysis of dynamics. This allows us to bring out the difficulty of developing economies. Empirically, we notice important divergences in country development from the beginning with distant dates of priming transition. Indeed,

[21] We can see in Appendix 2 that $n > 1$ for A sufficiently high, at least at the industrial steady state.

historically, whereas the industrial revolution began in England in the early eighteenth century, the industrialization process came later and more slowly for other countries (in France, it began 50 years after England; in Germany, Canada and United-States of America, 100 years after; in Japan and Russia, 120 years after),[22] not to mention developing countries where it happens only recently. Over the course of history, we have thus observed simultaneously economies in both regimes, the pre-industrial one and the industrial one. We will see that our model allows to explain these features, establishing in addition a link with pollution emissions.

The study of dynamics is carried out in a simple way, using a phase diagram. Considering the dynamic system (12), we are able to evaluate two phases lines ($\Delta x_{t-1} = 0$ and $\Delta k_t = 0$) delineating the space, and to compute the sense of variation of the variables in the different regions of the space. As illustrated in Figure 2, x_{t-1} decreases (increases) below (above) the $\Delta x_{t-1} = 0$ locus, while k_t increases (decreases) below (above) the $\Delta k_t = 0$ locus. Therefore, the industrial steady state (E_2) is stable, whereas the pre-industrial one (E_1) corresponds to an unstable saddle equilibrium, leading to a poverty trap.

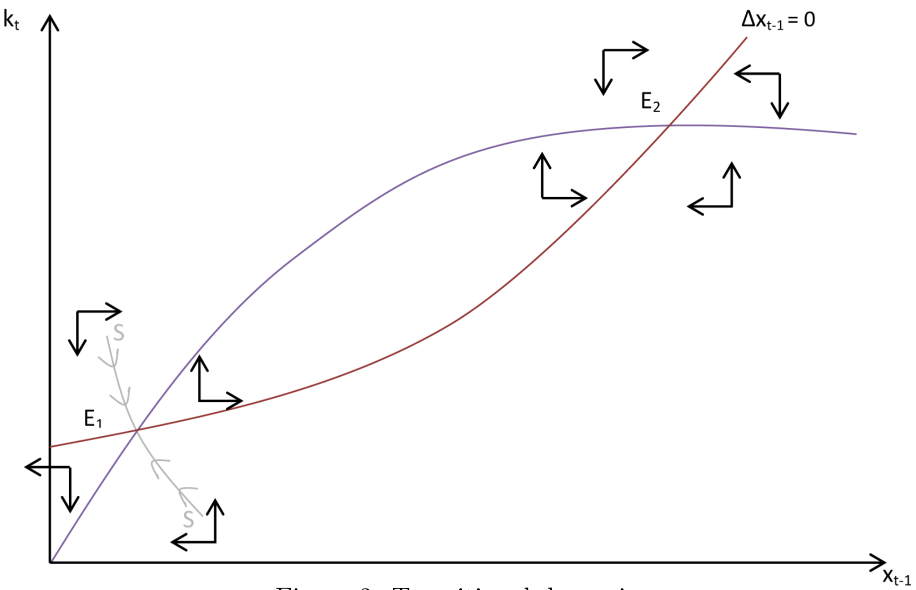

Figure 2: Transitional dynamics

These results are summarized in the following proposition.

Proposition 2 *For β sufficiently weak, the industrial steady state (E_2) is stable and the pre-industrial one (E_1) is an unstable saddle point with a stable manifold (SS). Below (SS), the economy is stuck on a poverty trap, whereas above (SS), the economy converges to the industrial steady state.*

Proof. See Appendix 3. ■

For initial conditions such that the economy starts above the border (SS), wealth is high enough to generate an income effect which allows a higher fertility, a more substantial bequest and a larger individual consumption. Therefore, the economy may develop and converge, in the long run, on a balanced growth path identified by the industrial steady state (E_2). This occurs because there are restoring forces acting against an infinite progress and leading the economy toward such a steady state. Firstly, the rearing cost of children (β), which is a cost per child, does not stop to grow with child number. Secondly, since adults have a distaste effect of pollution on consumption, they make a

[22] See Bairoch (1997).

trade-off between these two variables and prefer to decrease their consumption growth when pollution becomes too large. Finally, decreasing returns on capital limits directly the income effect and so the increase of wealth.

When the initial conditions are located below the (SS) curve, the economy is relegated to a poverty trap. Indeed, the individual income is too low with respect to rearing cost per child. Hence households have no incentive to increase the number of children and the bequest in terms of wealth, maintaining the economy into the trap. In this case, the economy is characterized by a low capital intensity, population growth and pollution.

Being interested in the development process, we highlight two different scenarios depending on initial conditions. At given weak level of capital intensity k, the economy can experience two different configurations of dynamics.

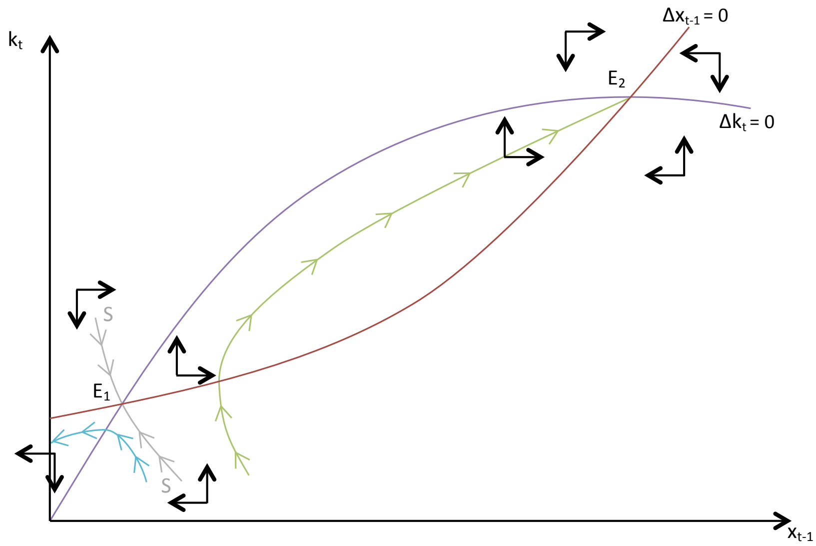

Figure 3: Two scenarios of developing countries dynamics

Either n is high enough, *i.e.* above the poverty trap (green manifold), the economy takes off. Firstly, the population growth decreases because the rearing cost β is too high relatively to wealth. It has a direct effect on capital per capita k which increases mechanically. Then, the capital accumulation is sufficient to generate an income effect allowing higher consumption, capital intensity and population growth. These increases generate also an increase in pollution, corresponding to the first part of the environmental Kuznets curve where pollution worsen as country's income grows.

In the second scenario, n is too low, and economy is actually stuck in the poverty trap. The fist step is identical, population growth decreases, which induce an increase in capital per capita. But k does not rise sufficiently and so fail to ensure the subsistence of a larger population. In longer run, the lack of population introduces a lack of workforce and makes the economy poorer. The capital accumulation is not enough to generate the economy take-off. Moreover, the limited consumption and population growth bring on a weak pollution level.

The coexistence of the poverty trap and the industrial stable steady state illustrates the heterogeneous experiences of countries during the convergence process. This also explains that at the same time some countries were already engaged in the industrial process while others were still stuck in the pre-industrial trap.

3.3 Impact of a technological shock

The question we address now is the following: could a permanent technological shock, that we associate to a major technological innovation, reverse the dynamics of an economy located in the trap, allowing it to converge to the stable industrial steady state?

To keep things as simple as possible , we already specify that we consider a basic production sector. We interpret a technological change as a permanent improvement of technology, more precisely as a permanent and positive shock on the productivity of factors A. As illustrated in Figure 4, the curve $\Delta x_{t-1} = 0$ shifts down and the stable manifold (SS) is pushed down toward (0,0) when A increases, leading to the two new steady states $E_1^{'}$ and $E_2^{'}$. The increase of productivity facilitates the beginning of the mechanism of growth and convergence towards the industrial steady state, by increasing instantaneously output, and then, by encouraging the development process described previously.

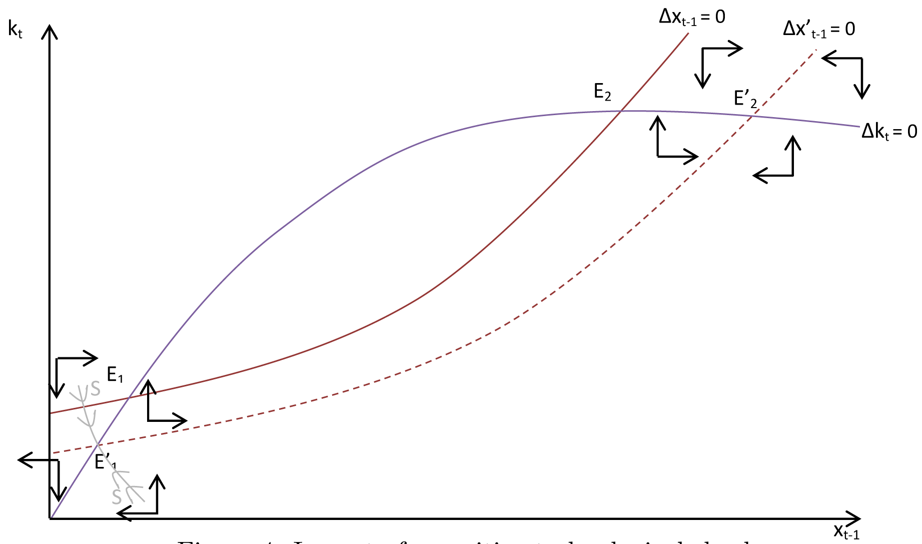

Figure 4: Impact of a positive technological shock

We can summarize the results about the effects of a positive and permanent technological shock in the following proposition.

Proposition 3 *For β sufficiently weak, a permanent and positive shock reduces the pre-industrial trap, so that:*

- *an economy in the low-development trap but sufficiently close to E_1, will converge to the industrial steady state;*
- *an economy in the poverty trap may always tend to the industrial steady state if the technological shock is large enough.*

As described in Figure 4, following the technological shock, the *old* unstable steady state E_1 enters the region where one converges to the *new* industrial steady state $E_2^{'}$. Thus, such a shock favors the transition to the industrial long-term equilibrium and the escape from the poverty trap which maintains the economy at a low development level. These results promote technological transfer policies toward the least developed countries, allowing them to escape the trap permanently.

As already emphasized, this technological shock may illustrate a major innovation at the beginning of industrialization. For most of the countries, this process was indeed continuous and progressive, which explains why historians prefer the expression industrialization than industrial revolution. Our model points up these features: a strong enough technological shock conducts the economy on a new dynamic path converging, in the long run, to an equilibrium with higher capital intensity, population growth and pollution. Hence, it reproduces the economic development, the environmental damage associated and the role of a permanent technological shock in the priming of this mechanism.

However, for a given technological shock, some economies will follow an industrialization path, whereas others, characterized by a lower initial level of economic development, will not escape the trap and will need further innovations to engage in the industrialization process.

4 Conclusion

In this paper, we develop a simple overlapping generations model, to explain the industrialization process, characterized not only by an increase of capital intensity and population growth, but also a rise of pollution. We bring out the role of finite-lived agents in this process through their altruism and their family choices. A key feature of our explanation is the introduction of an environmental altruism, which stipulates that adults agree to leave a lesser natural environment quality to their children, if they expect an improvement of economic environment. A second important feature of our framework is the introduction of a constant rearing cost per child in terms of the final good, which seems a realistic assumption when one focuses on the period of industrial revolution.

We show that the economy may converge to an industrial steady state with high capital intensity, population growth and pollution. However, when the initial conditions on wealth and population size are too low, the economy is relegated to a poverty trap. Finally, a permanent technological shock that we associate to a major innovation promotes the convergence to the industrial steady state.

5 Appendix

5.1 Appendix 1: Proof of Lemma 1

Substituting $g(x)$ and $h(x)$, given by (7) and (8) respectively, in the system (13), we get:

$$\left\{\begin{array}{rcl} \Psi_1(x) & = & \left[\frac{1}{A}\left(\beta(1-\alpha)+x\left[1+\frac{1+\beta a\gamma^{\frac{-1}{1+\mu_3}}x^{\frac{1}{1+\mu_3}}}{\epsilon_1+\epsilon_2\ a\ \gamma^{\frac{\mu_3}{1+\mu_3}}x^{\frac{1}{1+\mu_3}}}\right]\right)\right]^{\frac{1}{s}} \\ \\ \Psi_2(x) & = & \frac{x\gamma^{\frac{1}{1+\mu_3}}}{(1-\alpha)\gamma^{\frac{1}{1+\mu_3}}+a\ \frac{x^{\frac{2+\mu_3}{1+\mu_3}}}{\epsilon_1+\epsilon_2\ a\ \gamma^{\frac{\mu_3}{1+\mu_3}}x^{\frac{1}{1+\mu_3}}}} \end{array}\right.$$

with $\gamma \equiv \beta\frac{\epsilon_1}{\epsilon_2}\ \frac{1+\mu_3}{\mu_3}$.

Study of the function Ψ_1

We have $\Psi_1(0) = \left[\frac{\beta(1-\alpha)}{A}\right]^{\frac{1}{s}} > 0$ and $\lim_{x\to+\infty}\Psi_1(x) = +\infty$. Computing the first order derivative of $\Psi_1(x)$, we obtain:

$$\begin{array}{rcl} \Psi_1'(x) & = & \frac{1}{s}\frac{1}{A}\frac{x^{\frac{1}{1+\mu_3}}\left[2\epsilon_1\epsilon_2\ a\ \gamma^{\frac{\mu_3}{1+\mu_3}}+\frac{\mu_3}{1+\mu_3}\epsilon_2\ a\ \gamma^{\frac{\mu_3}{1+\mu_3}}+\frac{2+\mu_3}{1+\mu_3}\ a\ \gamma^{\frac{-1}{1+\mu_3}}\beta\ \epsilon_1\right]+x^{\frac{2}{1+\mu_3}}\left[\epsilon_2^2\ a^2\ \gamma^{\frac{2\mu_3}{1+\mu_3}}+\beta a^2\epsilon_2\gamma^{\frac{-1+\mu_3}{1+\mu_3}}\right]+\epsilon_1(1+\epsilon_1)}{\left(\epsilon_1+\epsilon_2\ a\ \gamma^{\frac{\mu_3}{1+\mu_3}}x^{\frac{1}{1+\mu_3}}\right)^2} \\ & & \left[\frac{1}{A}\left(\beta(1-\alpha)+x\left[1+\frac{1+\beta a\gamma^{\frac{-1}{1+\mu_3}}x^{\frac{1}{1+\mu_3}}}{\epsilon_1+\epsilon_2\ a\ \gamma^{\frac{\mu_3}{1+\mu_3}}x^{\frac{1}{1+\mu_3}}}\right]\right)\right]^{\frac{1-s}{s}} > 0 \end{array}$$

meaning that $\Psi_1(x)$ is a strictly increasing function, with $\Psi_1'(0) = \frac{1}{s}\frac{1}{A}\left(1+\frac{1}{\epsilon_1}\right)\left[\frac{1}{A}\beta(1-\alpha)\right]^{\frac{1-s}{s}}$.

Study of the function Ψ_2

We have $\Psi_2(0) = 0$ and $\lim_{x\to+\infty}\Psi_2(x) = \epsilon_2\,\gamma$. Using

$$\Psi_2(x) = \frac{x\gamma^{\frac{1}{1+\mu_3}}}{(1-\alpha)\gamma^{\frac{1}{1+\mu_3}} + a\,H(x)}\ , \quad \text{with}\ \ H(x) \equiv \frac{x^{\frac{2+\mu_3}{1+\mu_3}}}{\epsilon_1\ + \epsilon_2\ a\ \gamma^{\frac{\mu_3}{1+\mu_3}}\, x^{\frac{1}{1+\mu_3}}}$$

the first order derivative of $\Psi_2(x)$ is given by:

$$\Psi_2'(x) = \frac{\gamma^{\frac{1}{1+\mu_3}}\left[(1-\alpha)\gamma^{\frac{1}{1+\mu_3}} + aH(x)\right] - x\gamma^{\frac{1}{1+\mu_3}}aH'(x)}{\left[(1-\alpha)\gamma^{\frac{1}{1+\mu_3}} + aH(x)\right]^2}$$

with $H'(x) = \frac{\epsilon_1\ \frac{2+\mu_3}{1+\mu_3}x^{\frac{1}{1+\mu_3}} + x^{\frac{2}{1+\mu_3}}\epsilon_2\ a\ \gamma^{\frac{\mu_3}{1+\mu_3}}}{\left[\epsilon_1\ +\epsilon_2\ a\ \gamma^{\frac{\mu_3}{1+\mu_3}}\, x^{\frac{1}{1+\mu_3}}\right]^2} > 0$.

Therefore,

$$\Psi_2'(x) \geqslant 0 \Leftrightarrow \gamma^{\frac{1}{1+\mu_3}}(1-\alpha) \geqslant J(x)\ , \quad \text{with} \quad J(x) \equiv \frac{a\epsilon_1\ x^{\frac{2+\mu_3}{1+\mu_3}}\frac{1}{1+\mu_3}}{\left[\epsilon_1\ + \epsilon_2\ a\ \gamma^{\frac{\mu_3}{1+\mu_3}}\, x^{\frac{1}{1+\mu_3}}\right]^2}$$

Since $J(x)$ is strictly increasing for $x > 0$, $J(0) = 0$ and $\lim_{x\to+\infty}J(x) = +\infty$, there exists a unique x^* such that $\Psi_2'(x) \geqslant 0$ for all $x \leqslant x^*$, while $\Psi_2'(x) \leqslant 0$ for all $x \geqslant x^*$. Finally, we have $\Psi_2'(0) = \frac{1}{(1-\alpha)}$.

5.2 Appendix 2: Proof of Proposition 1

Existence of two steady states

We have $\lim_{x\to+\infty}\Psi_1(x) = +\infty$ and $\Psi_2(0) = 0$. Furthermore, when β tends to 0 (but stays strictly positive), $\Psi_1(0)$ and $\lim_{x\to+\infty}\Psi_2(x)$ become arbitrarily close to 0. Finally, $\Psi_2'(0) = \frac{1}{(1-\alpha)} > 1$, while $\Psi_1'(0) = \frac{1}{A}\frac{1}{s}\left(1+\frac{1}{\epsilon_1}\right)\left(\frac{1}{A}\beta(1-\alpha)\right)^{\frac{1-s}{s}}$ tends to 0 when β tends to 0. Since $\Psi_1(x)$ and $\Psi_2(x)$ are continuous functions, we deduce that there are two solutions satisfying $\Psi_1(x) = \Psi_2(x)$ (see also Figure 5). By continuity, there exist two steady states for β sufficiently low, namely (x_1, k_1) and (x_2, k_2).

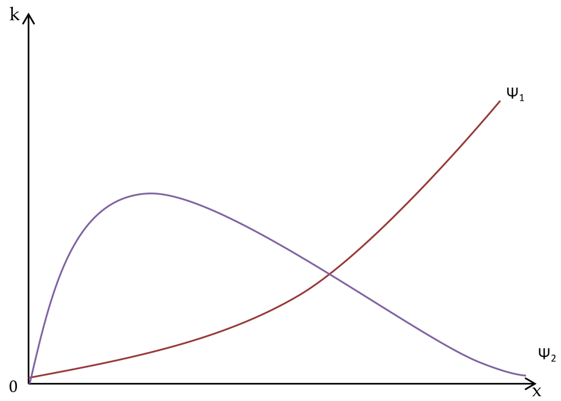

Figure 5: Representation of $\Psi_1(x)$ et $\Psi_2(x)$ when $\beta \to 0$

Main features of the steady states:
To fix ideas, consider that $x_1 < x_2$. Since $\Psi_1(x)$ is strictly increasing, we have $k_1 < k_2$. Recalling that $g(x)$ is decreasing and $h(x)$ is increasing, we deduce that $\Pi_2 < \Pi_1$ and $c_2 > c_1$.
According to (1), we have:

$$\frac{P_{t+1}}{P_t} = (1-\alpha) + \frac{aN_t c_t}{P_t} \tag{14}$$

At steady state, Π_t is constant, which means that pollution and population grow at the same rate, n. Thus, equation (14) rewrites:

$$n = (1-\alpha) + \frac{ac_t}{\Pi_t} \tag{15}$$

Since $c_2 > c_1$ and $\Pi_2 < \Pi_1$, we get $n_2 > n_1$.
Using $N_0 = 1$, $N_t = n^t$ on a steady state. We can therefore rewrite (15) as:

$$n = (1-\alpha) + \frac{an^t c_t}{P_t}$$

$$\Leftrightarrow P_t = \frac{a\, n^t c_t}{n-1+\alpha}$$

Because Π_t and c_t are strictly positive, we have $n > 1-\alpha$ (see (15)). We deduce that $P_{2t} > P_{1t}$.

5.3 Appendix 3: Proof of Proposition 2

To prove this proposition, we construct the phase diagram associated to the dynamic system (12). See also Figure 2. Equation (12 (B)) is equivalent to $\frac{x_t}{k_{t+1}} = \frac{(1-\alpha)g(x_{t-1})+a\ h(x_t)}{g(x_t)}$. Therefore, equation (12 (A)) can be rewritten as:

$$k_t = \left[\frac{1}{A}h(x_t) + x_t + \beta\frac{(1-\alpha)g(x_{t-1}) + a\ h(x_t)}{g(x_t)}\right]^{\frac{1}{s}} \tag{16}$$

i.e. k_t can be written as a function of x_t and x_{t-1}: $k_t \equiv \Theta_1(x_t, x_{t-1})$, where Θ_1 is increasing in the first argument and decreasing in the second one. Note that $\Theta_1(x_t, x_t)$ is the phases line $\Delta x_{t-1} = 0$, and corresponds to the curve $\Psi_1(x_t)$, relevant for the steady state analysis. We also have:

$$x_t > x_{t-1} \Leftrightarrow \Theta_1(x_t, x_{t-1})_{|x_t > x_{t-1}} > \Theta_1(x_t, x_{t-1})_{|x_t = x_{t-1}}$$

Therefore, when k_t is above (below) $\Theta_1(x_t, x_t)$, we get $x_t > x_{t-1}$ ($x_t < x_{t-1}$).
Now, using (16), we implicitly define $x_t \equiv \Theta_3(k_t, x_{t-1})$, where Θ_3 is increasing in both arguments. Substituting this in (12 (B)), we obtain:

$$k_{t+1} = \frac{\Theta_3(k_t, x_{t-1}) \quad g(\Theta_3(k_t, x_{t-1}))}{(1-\alpha)g(x_{t-1}) + a\ h(\Theta_3(k_t, x_{t-1}))} \equiv \Theta_2(k_t, x_{t-1}) \tag{17}$$

where Θ_2 is increasing in x_{t-1} at least for x_{t-1} not too large. When $k_{t+1} = k_t$, equation (17) becomes:

$$k_t = \frac{\Theta_3(k_t, x_{t-1}) \quad g(\Theta_3(k_t, x_{t-1}))}{(1-\alpha)g(x_{t-1}) + a\ h(\Theta_3(k_t, x_{t-1}))} \tag{18}$$

which implicitly defines k_t as a function of x_{t-1}. Using that Θ_2 is increasing in x_{t-1},[23] a raise of x_{t-1}

[23] This may require that x_{t-1} is not too large.

above its level defined in (18) implies:

$$\theta_2(k_t, x_{t-1}) > k_t \Leftrightarrow k_{t+1} > k_t$$

Thus, when x_{t-1} is below the locus $k_{t+1} = k_t$, $k_{t+1} > k_t$, whereas above this second phase line, $k_{t+1} < k_t$.

Using all these elements, we can construct the phase diagram drawn in Figure 2 and deduce Proposition 2.

References

[1] Allais M. (1947), Économie et Intérêt, *Imprimerie Nationale, Paris.*

[2] Andreoni, J. (1989), "Giving with Impure Altruism: Applications to Charity and Ricardian Equivalence", *Journal of Political Economy* 96, 1447-1458.

[3] Bairoch, P. (1997), Victoires et Déboires: Histoire Economique et Sociale du Monde du XVIe siècle à nos Jours, *Gallimard, collection Champs histoire.*

[4] Barro, R. J. (1974), "Are Government Bonds Net Wealth?", *Journal of Political Economy* 82, 1095-1117.

[5] Barro, R. J. and Becker, G. S. (1989), "Fertility Choice in a Model of Economic Growth", *Econometrica* 57, 481-501.

[6] Becker, G. S. and Barro, R. J. (1988), "A Reformulation of the Economic Theory of Fertility", *The Quarterly Journal of Economics* 103, 1-25.

[7] Becker, G. S. (1993), A Treatise on the Family., *Harvard University Press* enlarged edition.

[8] Brock, W.A. and Taylor, M.S. (2005), "Economic Growth and the Environment: a Review of Theory and Empirics", in P. Aghion and S.N. Durlauf, eds, *Handbook of Economic Growth* Ed1, Vol. 1, 1749-1821.

[9] Brown, J. C. (1990), "The Condition of England and the Standard of Living: Cotton Textiles in the Northwest, 1806-1850", *Journal of Economic History* 50, 591-615.

[10] Chu, C. Y. C. and Yu, R. R. (2002), "Population Dynamics and the Decline in Biodiversity: a Survey of the Literature", *Population and Development Review* 28, S126-S143.

[11] Crutzen, P. I. and Stoermer, E. F. (2000), "The Anthropocene", *IGBP Newsletter* 41, 12.

[12] Dasgupta, P. S. (2003), "Population, Poverty, and the Natural Environment", in K.-G. Maler and J. Vincent, eds, *Handbook of Environmental Economics*, Vol. 1, 191-247.

[13] Diamond, P.A. (1965), "National debt in neoclassical growth model", *American Economic Review* 55, 1126-1150.

[14] Ehrlich I. and Lui F. (1997), "The Problem of Population and Growth: A Review of the Literature from Malthus to Contemporary Models of Endogenous Population and Endogenous Growth", *Journal of Economic Dynamics and Control* 21, 205-242.

[15] Galor, 0. (2005), "From Stagnation to Growth: Unified Growth Theory", in P. Aghion and S.N. Durlauf, eds, *Handbook of Economic Growth* Ed1, Vol. 1, 171-293.

[16] Galor, 0. and Weil, D.N. (2000), "Population, Technology and Growth: From Malthusian Stagnation to the demographic Transition and Beyond", *American Economic Review* 110, 806-828.

[17] Gradus, R. and Smulders, S. (1993), "The Trade-off between Environmental Care and Long-term Growth; Pollution in Three Prototype Growth Models," *Journal of Economics* 58(1), 25-51.

[18] Grossman, G. M. and Krueger, A. B. (1991), "Environmental Impacts of a North American Free Trade Agreement", *National Bureau of Economic Research (ed.), Working Paper 3914, Cambridge MA.*

[19] Horrel, S. and Humphries J. (1995), "The Exploitation of Little Children": Child Labor and the Family Economy in the Industrial Revolution", *Explorations in Economic History.*

[20] Howarth, R.B. and Norgaard R. (1992), "Environmental Valuation under Sustainable Development", *American Economic Review* 82, 473-477.

[21] John, A. et Pecchenino R. (1994), "An Overlapping Generations Model of Growth and the Environment",*The Economic Journal* 104, 1393-1410.

[22] John, A. Pecchenino, R. Schimmelpfenning, D. and Schreft D. (1995), "Short-lived Agents and the Long-lived Environment", *Journal of Public Economics* 58, 127-141.

[23] Jouvet, P. A., Michel, P. and Vidal, J.-P. (2000), "Intergenerational Altruism and the Environment", *Scandinavian Journal of Economic* 102(1), 135-150.

[24] Leguay, J.P. (1999), La Pollution au Moyen Age, *Gisserot-Histoire.*

[25] Michel, P. and Rotillon, G. (1995), "Disutility of Pollution and Endogenous Growth", *Environmental and Resource Economics* 6(3), 279-300.

[26] Ono, T. (1996), "Optimal Tax Schemes and the Environmental Externality", *Economics Letters* 53, 283-289.

[27] Panayotou, T. (1995), "Optimal Tax Schemes and the Environmental Externality", *Economics Letters* 53, 283-289.

[28] Ramsey, F. (1928), "A Mathematical Theory of Savings", *Economic Journal* 38, 543-559.

[29] Robinson, J. A. and Srinivasan, T. N. (1997), "Long-term Consequences of Population Growth: Technological change, Natural Resources, and the Environment", in M. R. Rosenzweig and O. Stark, eds., *Handbook of Population and Family Economics*, Vol. 1, 1175-1297.

[30] Samuelson, P. (1958), "An Exact Consumption-Loan Model of Interest With or Without the Social Contrivance of Money", *Journal of Political Economics* 66 (6), 467-482.

[31] Van Alstine, J. and Neumayer, E. (2010), "The Environmental Kuznets Curve", in K.P. Gallagher (Eds.), *Handbook on Trade and the Environment*, pp. 49-59.

[32] Wrigley, E.A. and Schofield, R.S. (1981), The Population History of England 1541–1871: A Reconstruction. *Harvard University Press*, Cambridge, MA.

[33] Williamson, J. G. (1985), "Did British Capitalism Breed Inequality?" *Boston: Allen and Unwin*, chap. 1-4.

[34] Xepapadeas, A. (2004), "Economic Growth and the Environment", in K.-G. Mäler et J.R. Vincent (Eds.), *Handbook of Environmental Economics, Vol. 3, Chap. 3, North-Holland.*

[35] Zalasiewicz, J. *et al.* (2008), "Are We Now Living in the Anthropocene", *GSA Today* 18 (2), 4-8.